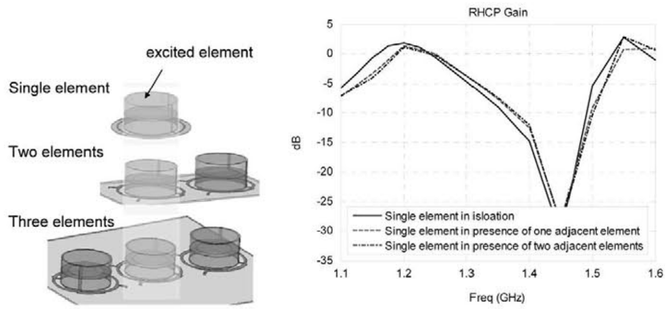

Fig. 11. Gain performance in presence of the adjacent elements.

for this analysis was 40 mm and the non-excited elements were terminated at 50 Ω. Thus, this hybrid design can be used to populate a small anti-jamming GPS array without adverse coupling effects.

IV. Conclusion

A small, compact and single-fed CP stacked patch was presented to cover all GPS bands. A key feature of this design is the integrated branch-line hybrid, which achieves CP excitation for the stacked patches. The small aperture size ($\lambda/8$ at L5/1176 MHz) and single feed property makes this antenna quite attractive for small GPS arrays. The design was verified with measurements. Also, the final hybrid design was adjusted for reduced coupling when placed in an array setting.

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A High-Isolation, Wideband and Dual-Linear Polarization Patch Antenna

Mariano Barba

***Abstract*—The design of a dual-polarization stacked patch antenna to be used in GSM-UMTS base station arrays is presented. The patch shows a high matching level in a broadband and isolation between elements that make it a suitable radiating element for base station arrays. Moreover, the most relevant achievement of this element is the isolation between the two polarization ports of the same element in the antenna operating bandwidth. A prototype has been manufactured and measured. The measurements, that match the design objectives, are also presented.**

***Index Terms*—Broadband antennas, dual polarized antennas, patch antennas.**

I. Introduction

Patch array technology has been applied to base station antennas in mobile communications systems for many years, because of their well-known characteristics of low profile, potential low cost, reliability and flexibility in achieving contoured beams. Radiating elements must provide sufficient bandwidth, low levels of cross-polarization, low back radiation, high efficiency and power handling. With the introduction of the new UMTS services, also known as 3 G, developing antennas covering the GSM1800 and UMTS bands has become very attractive. This band covers from 1710 to 2170 MHz, thus implying a 24% bandwidth.

It is well known that the one of most significant disadvantages of planar antennas is their narrow bandwidth. Consequently, some techniques have to be applied in order to reach the desired bandwidth. In addition, it is advisable to reach values of return losses as low as possible to obtain an element that allows a simple design of array antennas. However, as a result of the bandwidth improvement, other requirements that have to be considered in the array design and that are critical specifications for an array design are degraded. Therefore, a careful design balancing all of the requirements has to be made. On the other hand, base station antennas are considered as a mass production product, so considerations like low cost, simplicity and ease of assembly have to be taken into account.

In base station antennas, it is common the use of two orthogonal linear polarizations ($\pm 45^\circ$) to improve the system performances by polarization diversity. In mobile communications, isolation between ports greater than 30 dB is usually required, thus implying that the isolation of the two ports in the same radiating element has to be better than this value.

Dual polarization patches are also known for both uses: dual linear polarization or circular polarization. (In this case, a dual linear patch is used and the two inputs are fed with the same amplitude and a 90° phase shift). Several solutions have been proposed to obtain dual polarization in slot coupled patches, which is the case considered in this paper. One of the most common solutions consists of using off-set slots [1]–[3]. Other solutions using crossing slots and two feeding points in one or two slots [4], [5] or having crossing slots and lines in different layers [6], [7] have been reported.

TABLE I
MAIN SPECIFICATIONS

Parameter	Design	Prototype
Band	1690 MHz-2190 MHz	1710 MHz-2170 MHz
Return Loss	<-23 dB	<-20 dB
Coupling Between Ports	<-36 dB Typical < -33 Maximum	<-33 dB Typical <-33 Maximum
Front to back ratio	>25 dB	>25 dB

In general, the design of a patch having high isolation results in antennas with narrow bands or high values for return losses (RL). For example, in [1] and [3] bandwidths from 17.2% to 21% with isolations from 30 to 36 dB are found considering -10 dB for return losses. The antennas presented in [2] and [4] show high values of matching level ($\mathrm{RL} < -20$ dB) and isolation (35 dB), in a band of 100 MHz at 7.7 GHz in [2] and from 1.85 GHz to 1.99 GHz in [4].

The antenna proposed in [7] has a 52% bandwidth for isolation values of 39 dB at -10 dB return loss. This matching level is useful for many applications but it is not advisable to design arrays for base station antennas. Besides, the solution proposed in [7] uses two layers (and boards) for the input signals, while the antenna has the input lines in the same layer of the same board. The use of two layers increases the complexity and mainly the cost since, it is known, RF substrates and the etching drive to ones of the most important contributions in the antenna cost.

On the other hand, when high bandwidths for high matching levels are obtained, the isolation performances degrade. In [8] an antenna with a bandwidth greater than the 20% for return losses of -14 dB shows isolation greater than 25 dB.

This communication proposes a dual polarization patch antenna having high matching level and high isolation between polarization on the same element that make it suitable for array antenna implementation. The design considers the bandwidth specification for return losses and isolation, with targeted values of -22 dB and 33 dB, respectively for the two ports of the same element in the band as prototype aims. Therefore, this communication proposes a geometry that simultaneously reaches large bandwidths with a low level of isolation simultaneously. The main innovation of this communication is found in the geometry of the slot which is shaped with a narrow central part to keep the high isolation values and a wider part to obtain high coupling between the lines and the patches to allow high matching level in a wide band.

It also addresses other critical specifications that would allow it to be used as radiating element of a base station antenna: coupling between elements and back radiation. The designed radiating element is a two-stacked patch antenna, which is fed to the input microstrip line by means of a slot. The simulations show that the main goals are matched.

A prototype and its measurements are also presented, showing that the main challenges of the design: low return losses and high isolation between ports in a 25% band have been overcome in this case.

II. SPECIFICATIONS

The main requirements for the element are listed in Table I. Some tolerances can be critical in patch antennas. Therefore, to obtain the design specification, some margins have to be added to the prototype or production requirements. For that reason, two specifications are considered.

As has already been mentioned, high values of the matching level are required because the aim of this development is to obtain an element for an array antenna. Therefore, the optimum situation would be the one that allows an independent design of the radiating elements and the feed network. Of course this is not possible, and a complete evaluation of the feed network loaded with the radiating elements has to be carried out. However the best situation from the engineering point of view is the one that requires minor redesigns and corrections.

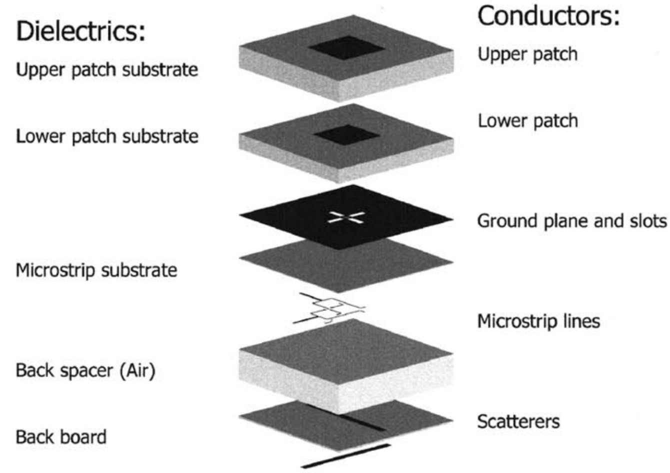

Fig. 1. Antenna architecture.

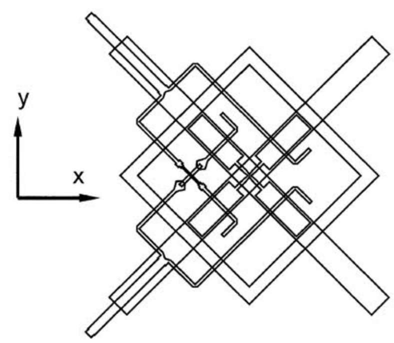

Fig. 2. Conductors views with coordinate system indication.

The specified isolation between ports for antenna arrays is typically about 30 dB. This is a very stringent requirement, and even using some compensation techniques in the array design, to reach this value, the isolation between the ports in the element used has to be better, the array design being simpler as this value is improved.

III. ANTENNA ARCHITECTURE AND DESIGN

It is well known that the aperture-coupled patch is the configuration that results in greater bandwidths. This is essential in this antenna because of the band requirement. The input line is a microstrip located on the back plane. Fig. 1 shows the general antenna architecture, which is discussed in more detail in the following sections. Fig. 2 shows the top view of conductors and an indication of the coordinate system.

A. Patches and Substrate

In order to achieve the matching bandwidth, two stacked patches with thick substrate are needed. Many references on stacked patches can be found; representative of them are [9]–[11]. Patches on high dielectric constant substrates have a lower bandwidth than patches on low dielectric constant substrates. As a consequence of this, it could be that the best substrate is air (in fact a patch printed on any dielectric with an air space). However, increasing the patch substrate dielectric constant reduces back radiation and reduces coupling between patches in an array, which are important requirements in this application. Therefore, to select the dielectric constant a trade off has to be made. It was

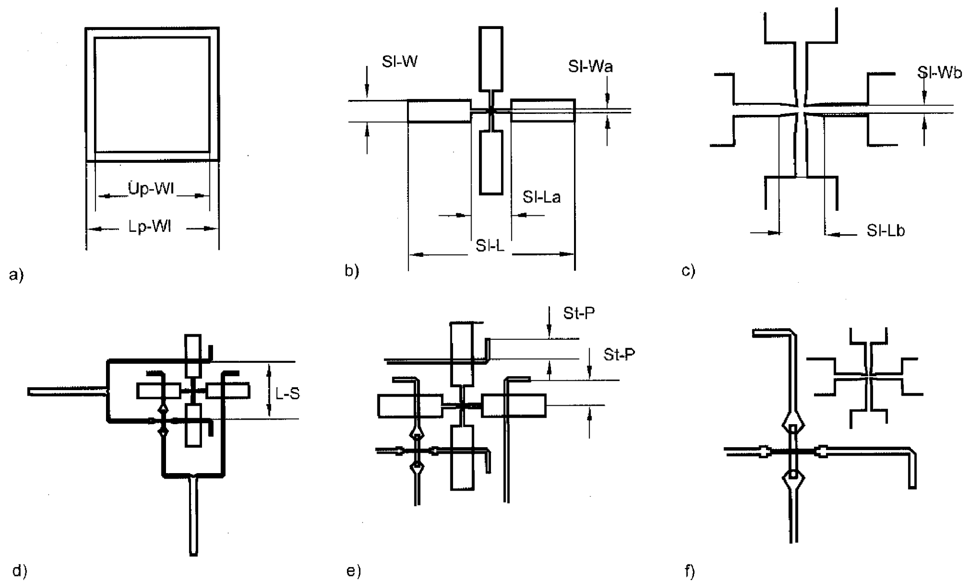

Fig. 3. Antenna geometry parameters. (a) Patches. (b) Slots. (c) Slot center detail. (d) Input lines. (e) Input lines stub. (f) Bridge detail.

found that a very appropriate value for the dielectric constant was in the range of 1.5–1.8. The material used in this design was Expanded PVC with a measured dielectric constant of 1.65 and delta tangent of 0.0035. This material has already been used in linear polarized patches for this application in [12].

Since a dual polarization with the same requirements is sought, the patches are squared.

To reduce costs, the patches are printed directly onto the substrate.

B. Slots

Because a large bandwidth is required and the patch substrate is thick, large coupling between the lines and the patches is needed. It is known that the centered slot configuration is the one that yields the greater coupling. So the two slots needed for a dual polarization antenna cross in the center. This solution consisting of crossing the slot has been already used as discussed in the introduction.

A dual slot configuration with one of the slots displaced from the center (offset slot) was researched, however the bandwidth and coupling requirements were not found, as it had features quite far from those specified.

Even with the centered slot configuration, the resulting slots in the first approach had large widths yielding very high coupling values in the specified band. The solution to achieving the bandwidth and coupling requirement was found by using a slot that has a wide width in the outer part of it, and narrow width in the inner part as can be seen in Figs. 1, 2, and 3. In addition, this allows a single polarization design, using the common design criteria for patch antennas and then it is only necessary to add the second polarization slot.

C. Input Lines and Substrate

To keep losses as small as possible, a high quality RF substrate has been used. The selected substrate was Arlon AD-320. It has a DK of 3.2 and a loss tangent of 0.003. The height of this substrate is 0.8 mm. Each slot is fed by a couple of microstrip lines over the wide part of the slot. These lines end in an open circuit having been the length of these sections chosen to compensate the inductance found at the resonance frequency.

The lines for both polarizations are printed on the same face of the board. To avoid line crossing, the open-ended line sections are bent as can be seen in Fig. 2. The impedance of these lines was selected at 80 Ω. A T-junction is used to go from the single input line to these lines, therefore the input line impedance is 40 Ω to allow the division. Since the input port impedance was set to 50 Ω, a quarter wavelength section is introduced to change from 50 Ω to 40 Ω.

TABLE II
DIELECTRIC PARAMETERS

Description	Material	Dielectric constant	Height (mm)
Upper patch substrate	Expanded PVC	1.65	18.0
Lower patch substrate	Expanded PVC	1.65	12.0
Microstrip substrate	Arlon AD320	3.2	0.8
Back Spacer	Air	1.0	25.0
Back board	FR4	4.1	1.5

TABLE III
GEOMETRY PARAMETERS

Description	Parameter	Dimension (mm)
Upper patch length and width	Up-Wl	38.32
Lower patch length and width	Lp-L	44.38
Slot length	Sl-L	37.20
Inner Slot length	Sl-La	9.00
Narrower slot section length	Sl-Lb	3.00
Slot width	St-W	4.80
Inner slot width	Sl-Wa	0.80
Narrower slot width	Sl-Wb	0.50
Bent stub length	St-L	4.87
First stub section position	St-P	5.52
Input lines separation	L-S	19.20
Input lines width		0.80
Input port line width		1.9

D. Air Bridge

Using the two input lines and bending them at the end, just one line cross is found. This cross cannot be avoided, so an air bridge was included in one of the lines. Because a very high isolation is desired, the bridge has to add as low a coupling as possible. To reduce the line coupling, the microstrip line has been narrowed; therefore the added inductance has been compensated by a capacitance load as can be seen

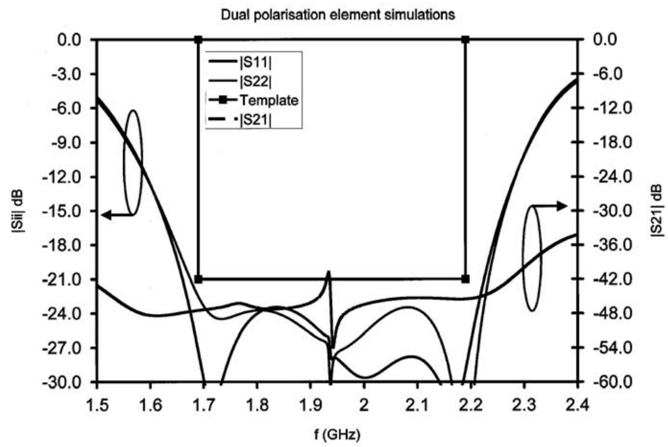

Fig. 4. Element simulations.

in Fig. 2 and Fig. 3(f). A similar situation is found in the bridge, since it has been implemented by a long wire that behaves as an inductor.

E. Back Scatterers

To reach the required back radiation specifications, a front to back (F/B) ratio greater than 25 dB, back scatterers printed on FR4 were introduced at a distance of 25 mm. By using them, the obtained F/B ratios in simulation were 26.8 dB at 1.7 GHz and 30.2 dB at 2.2 GHz, while the F/B ratio obtained without the reflectors were 14.2 dB and 18.8 dB at 1.7 GHz and 2.2 GHz, respectively. This solution is very similar to that used in [13] for aperture coupled patches with single polarization. It was applied in [14] to cancel the back radiation in coplanar fed patches with dual polarization. The results presented in [14] show that these scatterers are a good solution to cancel the back radiation in antenna configurations with single-feed dual-polarization, but it is stated that some reduction of the improvement was found at certain frequencies when used in dual-polarization antenna configurations with dual-fed, coplanar lines.

The results obtained in the prototype presented in this communication, which are very similar to those presented in [12], show that these scatterers are useful for antenna configurations of dual-feed, dual-polarization using microstrip lines.

F. Complete Geometry Parameters

Table II lists the substrates material stack, their heights and electrical properties.

Fig. 3 shows the geometrical parameters of the conductors and the values obtained for the design are listed in Table III.

IV. Simulations

The proposed antenna has been simulated with Agilent ADS2003 and ADS2005 Momentum. This software is a method of moment-based full wave electromagnetic simulator. The simulated return losses for each port of the structure are shown in Fig. 4. It can be seen that both ports match the design return loss specification. The coupling between ports is also shown in Fig. 4. The simulated port isolation widely matches the design specification as it can be observed.

A tolerance analysis would show that most of the results would match the design specification. It also would show that the most important deviations are consequence of the slot and substrate tolerances.

V. Prototype Measurements

From the described geometry, a prototype having two patches was manufactured. A photograph of this prototype is found in Fig. 5.

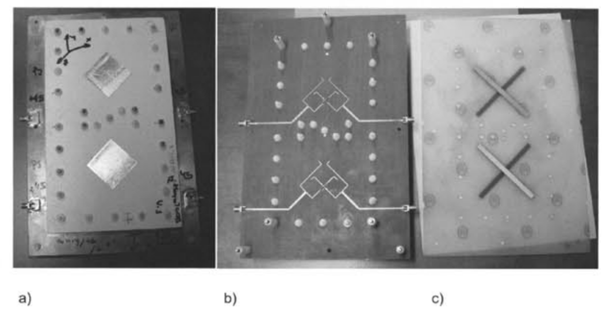

Fig. 5. Prototype photographs. (a) Top view. (b) Input lines view. (c) Back scatterers.

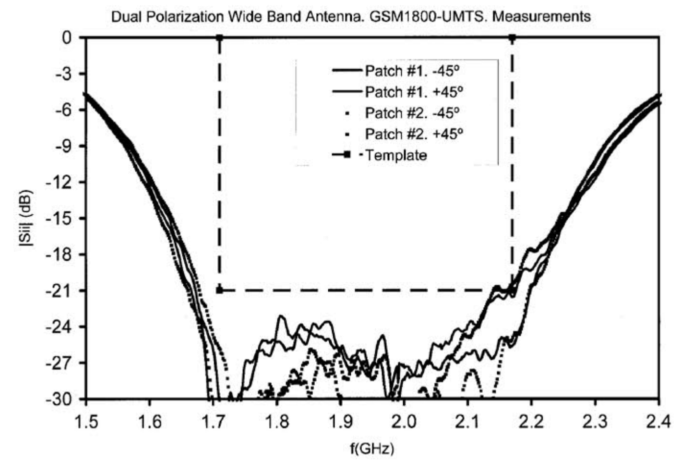

Fig. 6. Return losses measurements.

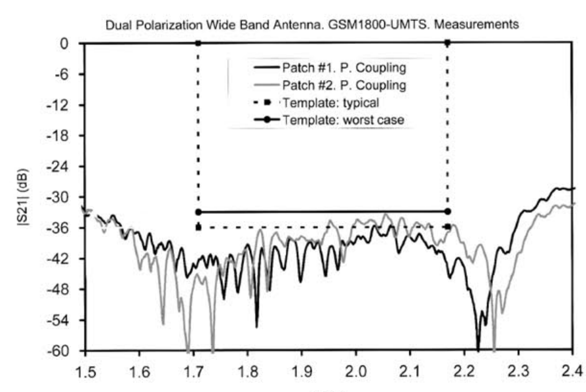

Fig. 7. Element coupling measurements.

Fig. 6 shows the measured return losses for the two polarizations of both patches. It can be seen that the measured values are several dBs better than the specified value, being then in the range of -24 dB as the simulation predicted.

Fig. 7 shows the measured coupling between ports of the same patch. Also in this case, it can be seen that the measured values are matching the specification, which was typically -36 dB, and -33 for the worst case. The obtained values in the whole band are considered excellent.

VI. Conclusion

The design of a dual-polarization stacked patch antenna has been presented. The main features of this element are a matching level and high isolation between ports achieved in a broad band. It also has low back radiation. These features make this element suitable to develop base station antennas.

A prototype has been manufactured and measured. The measured return losses (in the range of −24 dB) and isolation between polarizations of the same patch (in the range of 36 dB) for a 24% bandwidth show excellent antenna performances.

These elements will be used in reconfigurable antennas using advanced RF combination circuits.

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An Electromagnetically Coupled UWB Plate Antenna

Terence S. P. See and Zhi Ning Chen

***Abstract*—A broadband plate antenna operating at a frequency range of 3–12 GHz is proposed for ultrawideband (UWB) applications. The plate antenna consists of a shorting wall attached to the radiator. The radiator is excited by a parasitic L-shaped plate connected to a feeding probe. The vertical section of the L-shaped feeding plate is separated at a distance from the shorting wall. With the electromagnetic coupling between the feeding plate and the radiator, a broad impedance bandwidth is achieved. Also, the antenna with reduced size is able to achieve the stable radiation performance with gain greater than 4 dBi across the entire UWB band.**

***Index Terms*—Broadband antennas, electromagnetic coupling, ultrawideband (UWB) antennas.**

I. Introduction

Suspended plate antennas (SPAs) as a variation of patch antennas feature low-profile configurations, large impedance bandwidths, and low cost [1]. The radiating plate is about half-wavelength long at the lower edge of the operating frequency range. Usually, the impedance bandwidth of SPAs can reach up to 20%–40%.

A shorting wall can be placed at the center of the radiator to halve the length of a plate radiator where the electric field of the resonant mode is zero [2]. The bandwidth of the shorted radiator on a foam substrate is larger than that of a conventional suspended plate antenna [3]. However, it is also noted that the gain of the shorted plate antenna is about half of that of a conventional suspended plate antenna due to the halved radiator [3].

In ultrawideband (UWB) applications, it is desirable for the impedance bandwidth to be at least 50% in order to cover the lower UWB band of $3.1 - 5$ GHz or the upper band of 6–10.6 GHz or 100% for the entire UWB band of 3.1–10.6 GHz. Also, in order to prevent pulse distortions, the gain at certain directions of interest across the operating bandwidth should be consistent.

There are several ways to further enhance the bandwidth of the plate antenna, such as the addition of parasitic patches, either in stacked [4] or coplanar geometry [5], [6]. The stacked geometry has the disadvantage of increasing the thickness while the coplanar geometry increases the lateral size of the antenna. Another way to increase the impedance bandwidth is the use of L-probe feed, which introduces some capacitance to offset the feed inductance [7], [8]. The L-probe feed is able to achieve a bandwidth of about 35% [9]. The use of the shorting wall together with the L-probe feed is able to achieve a bandwidth of 40% [3].

In this communication, a broadband suspended plate antenna with a shorted wall operating from 3–12 GHz is proposed. A modified feeding probe is proposed to enhance the electromagnetic coupling between the radiator and the feeding plate for broadband impedance matching. Also, the antenna can achieve stable radiation performance with gain of >4 dBi across the operating bandwidth.

II. Antenna Design

Fig. 1 shows the geometry of the proposed plate antenna and the Cartesian coordinate system. The dimensions of the antenna are given